Draft Report
Human Health Risk Assessment for PCE in Soil and Soil Vapor

Villa Street Site, Mountain View, California

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January 2003

This document should be cited as:

Jones & Stokes. 2003. Draft Report: Human health risk assessment for PCE in soil and soil vapor at the Villa Street Site. January. (J&S 02282.02 001.) Bellevue, WA. Prepared for City of Mountain View Planning Department, Mountain View, CA.

Executive Summary

BACKGROUND

The property owners of the Villa Street (Jasco) site in Mountain View, California, in conjunction with the City of Mountain View, requested that a human health risk assessment (HHRA) be conducted to evaluate the potential risk to humans associated with exposure to perchloroethylene (PCE) in site soils and soil vapor. The work was performed due to concerns about upgradient PCE sources in groundwater. The HHRA is unrelated to Superfund issues or requirements. Although there is no currently no plan in place for site development, a HHRA was needed to evaluate the potential health risk associated with future residents and construction workers at the site.

The Villa Street site was listed by the U.S. Environmental Protection Agency (EPA) on its National Priority List in 1989, which in turn spawned numerous Superfund-related remedial activities designed to reduce concentrations of volatile organic compounds (VOC), including PCE. Various soil and groundwater investigations, remedial actions, and long-term groundwater monitoring surveys have been performed to document trends of VOCs over time. EPA issued a Record of Decision (ROD) in 1992 to formalize these efforts, codify requirements, and implement the site remedy (EPA 1992a). In 2002 EPA prepared an Explanation of Significant Differences (ESD) report as a 10-year follow-up since the promulgation of the ROD (EPA 2002).

EPA conducted a baseline risk assessment of the Villa Street site in 1989 (EPA 1989b) in support of the ROD to evaluate the potential for current and future health risks posed by VOCs present in soils and groundwater (soils were subsequently removed from the site during remediation activities). However, these earlier efforts did not consider PCE because: (a) it was not used or produced by Jasco, (b) no PCE was detected prior to preparation of the ROD, and (c) the contamination levels in site soils and groundwater have diminished markedly since the ROD was issued.

PCE was first detected in groundwater at the site during 1993. Consequently, Jasco conducted a series of investigations and discovered a PCE plume extending both upgradient and downgradient of the project site. Jasco prepared a *PCE Investigation Report*, which concluded that the presence of PCE was not associated with any past or present activities by Jasco or any other party on the Villa Street site (IT Corp. 2000). No potential responsible parties have been identified in association with this PCE plume.

In October 2002, Jasco measured PCE vapor concentrations in the vadose zone above the contaminated groundwater (Shaw 2002). As part of that survey, geotechnical samples were collected to measure the bulk soil density, moisture content, and vadose zone soil porosities. The results of the soil vapor survey allowed for incorporation of key site-specific data for use in the HHRA.

METHODOLOGY USED IN PREPARATION OF THE HHRA

This document was prepared in general accordance with EPA and California Office of Environmental Health Hazard Assessment (OEHHA) risk assessment guidelines (OEHHA 2000; EPA 2001; EPA 1989a). Potential sources of PCE, mechanisms of transport, and potential PCE exposure pathways were identified, which were then incorporated into a conceptual model which forms the basis of the exposure assessment. Existing PCE soil data for the project site were reviewed and evaluated by generally following the EPA's guidance for evaluating data useability in risk assessment (EPA 1992a).

The Johnson & Ettinger soil vapor intrusion model (EQM 2000) was used to derive exposure point concentrations via the inhalation exposure pathway for future residents. A simplified "box model" was used to estimate breathing zone PCE vapor concentrations that would occur inside the temporary excavation during the construction phase of the hypothetical underground garage. In addition, EPA and OEHHA guidelines were followed to derive exposures for all exposure pathways (e.g., EPA 1989a, EPA 1997; EPA 2001; OEHHA 2000). Potential exposures to receptors were quantified using conservative (upper-bound) assumptions, roughly equivalent to EPA's Reasonable Maximum Exposure (RME) guidelines.

If preliminary deterministic calculations indicated that EPA's target risk range values would be exceeded, probabilistic quantitative risk assessment techniques (using Crystal Ball®) would then be used to generate a range of cancer risk estimates to residents and construction workers. This model incorporates statistical ranges of numerous input parameters (contaminant data, exposure parameters, and toxicity values) to generate estimates of risk. Results are depicted as a range of estimated cancer risks for exposure to PCE. These ranges address both short- and long-term exposures in addition to locations potentially causing concern or associated with specific levels of risk.

A brief toxicological assessment was conducted to adopt the most appropriate toxicity benchmark values. For PCE this is a cancer potency slope value for the inhalation pathway of 1.5×10^{-1} $(mg/kg\text{-}d)^{-1}$ (OEHHA 2002). Estimated exposures were then combined with this cancer potency slope value to yield the quantitative estimates of human cancer risk.

Future residents and temporary construction workers are the only receptors identified for this risk assessment. The hypothetical inhalation pathway for each of these receptors was the only complete exposure pathway evaluated. Oral exposure to PCE in groundwater (drinking water pathway) was not evaluated because the site remedy specified in the ROD included a restrictive easement against the use of on-site shallow groundwater for drinking purposes that would remain in place until soil and groundwater cleanup standards are achieved. Any exposure pathway to PCE in soil was also considered incomplete because no PCE was detected above 12 feet below ground surface, which is the assumed depth of the hypothetical underground garage.

Cancer risks due to inhalation of PCE vapor were estimated for three exposure scenarios:

- C1, Temporary Construction Workers, assuming one year of exposure in a 12-foot-deep excavation;
- R1, Residential (without underground garage), assuming 30 years of exposure in a conventional slab-on-grade house; and
- R2, Residential (with underground garage), assuming an occupied above-ground house with an underground garage.

RISK CHARACTERIZATION

Table ES-1 summarizes the results of the probabilistic cancer risk assessment for each exposure scenario. The estimated cancer risks for the temporary construction workers and the "with underground garage" scenario are less than EPA's target risk range of 10^{-6} to 10^{-4} as stated in the ROD (EPA 1992b). However, the estimated 95th percentile cancer risk for the slab-on-grade (without underground garage) scenario is slightly greater than 10^{-6} (i.e. slightly greater than one-in-a-million cancer risk).

A deterministic cancer risk calculation for the most conservative scenario (slab-on-grade condominium without underground garage) was performed that was patterned after EPA's RME scenarios outlined in EPA (1989a). This scenario is regarded as still more conservative than the probabilistic approach due to the incorporation of only upper-bound, conservative values rather than statistically sampling from the entire data distribution of any given data set. This deterministic calculation yielded an estimated cancer risk of approximately four times greater than the probabilistic HHRA for that scenario (1.2×10^{-5}).

Table ES-1. Results of Risk Characterization by Individual Pathway and Receptor

Exposure Scenario		**Estimated Cancer Risk**	
Type of Exposure	**Scenario Code Designation**	**Upper 95th percentile (conservative)**	**Median (typical)**
Short Term	C1, Temporary Construction Workers	7.1×10^{-8}	3.0×10^{-8}
Long Term	R1, Residential (no underground garage)	3.0×10^{-6}	8.2×10^{-7}
Long Term	R2, Residential (unoccupied underground garage)	1.5×10^{-8}	3.5×10^{-9}

As shown in Table ES-1, risks predicted for the underground garage scenario were consistently lower than those predicted for the slab-on-grade (without underground garage) scenario by approximately a factor of two hundred. The difference in risks in the two scenarios was due to the fact that the underground garage would serve as a *de facto* vapor barrier, shielding the above-ground residential portion of the condominium from soil vapor migrating upward from the groundwater table.

CONCLUSIONS AND RECOMMENDATIONS

Following is a discussion of the conclusions from the HHRA.

Construction workers. The estimated risks to the construction workers present for 8 hours per day for 90 days at the site over a period of 1 year, excavating to a depth of 12 feet bgs, would have a negligible cancer risk, ranging from 7.1×10^{-8} to 3.0×10^{-8} (less than one in ten million) from exposure to PCE via the inhalation pathway.

Future residents (with underground garage). Future residents living in a condominium with an underground garage for 30 years would have an estimated cancer risk ranging from 1.5×10^{-8} to 3.5×10^{-9} (less than one in ten million) resulting from inhalation exposure to PCE vapors. This is also regarded as a negligible cancer risk. Risks predicted for the "underground garage scenario" were lower than those predicted for the "without underground garage scenario" by approximately a factor of two hundred. This difference is accounted for by the presence of the underground garage, which would serve as a *de facto* vapor barrier, shielding the above-ground residential portion of the condominium from soil vapor migrating upward from the groundwater table.

Future residents (without underground garage). Estimated risks to residents in the "without underground garage scenario" slightly exceeded EPA's target range of 10^{-4} to 10^{-6} (one-in-ten-thousand to one-in-a-million). The estimated inhalation cancer risk for a slab-on-grade home with no underground garage ranged from 8.2×10^{-7} (median value) to 3.0×10^{-6} (upper 95th percentile), if the home was built directly above the highest measured soil vapor concentrations. This risk level is not expected to be problematic or excessive due to the conservative nature of the assumptions underlying this estimate.

Soil exposure to PCE. Because PCE was only detected from soil at least 20 feet bgs (which is well below the limits for allowable soil excavation at the site) , neither future residents nor construction workers would be expected to be exposed to PCE in soil via incidental ingestion or dermal exposure.

Groundwater exposure to PCE. A deed restriction has been implemented to prevent use of on-site groundwater containing contaminant concentrations exceeding cleanup levels, discussed in Section 4, Element (ii) of the ROD. Moreover, it is prohibited to use site groundwater as a drinking water source. There is therefore no potential for exposure to PCE from site groundwater.

Uncertainty analysis. Risks to both the residents and the construction workers were predicted by using the conservative (upper 95th percentile) exposure scenarios, which were consistently higher than the risks predicted by using the median (typical) scenarios. Risk estimates for each of the inhalation pathways considered are expected to be highly conservative (protective) of each potentially exposed receptor group. For example, the hypothetical condominium unit was assumed to be constructed over the highest measured soil vapor concentrations at the site. Therefore actual risks to both future residents and construction workers would be lower than the estimated risks if future buildings are located in areas other than the assumed building location.

The modeled risks are also believed to be conservatively high because future residents were assumed live in weather-tight homes with windows closed year-round. This assumption minimizes the air exchange rate and maximizes the indoor-outdoor pressure differential, and therefore maximizes the modeled indoor PCE concentration. In reality, given the moderate weather conditions in Mountain View it is likely future residents would leave windows open much of the year, thereby ventilating any PCE vapor that could migrate through the floor.

Results from this risk assessment could be useful for formulating institutional controls, deed restrictions, and/or building guidelines specified under EPA's ESD report (EPA 2002) or any other documentation needed to support protective measures at the site.

Recommendations. Based on the foregoing analysis and conclusions, it is recommended that:

- No soil vapor barrier would be needed as part of construction (any underground garage or other structure would serve as an effective *de facto* soil vapor barrier).

- No additional institutional controls or deed restrictions will be needed to further mitigate or reduce residential or construction-related exposures to PCE in soil vapor at the Villa Street site.

- No long-term monitoring or further field investigations should be required because the conclusions from this HHRA are quite definitive.

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Human Health Risk Assessment for PCE in Groundwater, Soil, and Soil Vapor

Villa Street Site, Mountain View, California

1 INTRODUCTION AND BACKGROUND

The property owners of the Villa Street (Jasco) site in Mountain View, California, in conjunction with the City of Mountain View, requested that a human health risk assessment (HHRA) be conducted to evaluate the potential risk to humans associated with exposure to perchloroethylene (PCE) in site soils and soil vapor. The work was performed due to concerns about upgradient PCE sources in groundwater unrelated to Superfund issues or requirements.

The purpose of this document is to report findings concerning the potential for health risk to future residents and site workers associated with potential exposure to perchloroethylene (PCE) at the Villa Street site. The site is also known as the Jasco site because it was formerly occupied by the Jasco Chemical Corporation.

1.1 Background

This site was listed by the U.S. Environmental Protection Agency (EPA) on its National Priority List (used to define Superfund sites) in 1989, which in turn spawned numerous remedial activities. These have included various soil and groundwater investigations for contaminants of potential concern, all of which were volatile organic compounds (VOCs; IT Corp. 1998a, 1998b, 1998c and 1998d; IT Corp. 2000, 2001a and 2001b). Other activities have included remedial actions and periodic groundwater monitoring surveys. EPA issued its Record of Decision (ROD) to formalize these efforts and implement the site remedy (EPA 1992b). EPA has also recently issued its Explanation of Significant Differences (ESD) report (EPA 2002) as a 10-year follow-up since the promulgation of the ROD.

As part of these activities, EPA conducted a baseline risk assessment to evaluate the current and potential future health risks posed by VOCs present in soils (subsequently removed from the site during remediation activities) and groundwater of the Superfund site (EPA 1989b). The report concluded that the potential for exposure to contaminated soils via dermal absorption and/or incidental ingestion is "very low to non-existent" unless the soils were disturbed. Any future potential health risks would be based on exposures that could occur if untreated shallow zone groundwater was used for human consumption and residential development occurred on the site. However, the site remedy specified in the ROD includes a restrictive easement or deed restriction (Section 4, Element (i)) wherein restrictions against the use of on-site shallow groundwater for drinking purposes would remain in place until soil and groundwater cleanup standards were achieved. This evaluation did not consider PCE because it was not used by Jasco, no PCE was detected prior to preparation of the ROD, and the quality of site soils groundwater has improved markedly since the ROD was issued and contaminated soils were removed.

PCE was first detected in groundwater at the site during 1993. Consequently, Jasco conducted a series of investigations and discovered a PCE plume extending both upgradient and downgradient of the project site. Jasco prepared its *PCE Investigation Report* (IT Corp. 2000) that concluded the presence of PCE was not associated with any past or present activities by Jasco or any other party on the Villa Street site. No potentially responsible parties have been identified in association with this PCE plume.

There is also no current plan in place for eventual site development. However, due to the potential of future residential development on the Villa Street site, the property owners in conjunction with the City of Mountain View requested that a human health risk assessment be conducted to evaluate the potential risk to humans associated with exposure to PCE in site groundwater, soils, and soil vapor.

1.2 Overview of Approach

This human health risk assessment was performed according to widely accepted federal and state guidelines for conducting risk assessment (e.g., EPA 1989a, 2001; OEHHA 2000). The general steps followed to conduct the risk assessment are:

1. Identify potentially exposed human receptors and associated exposure pathways.

2. Review and evaluate existing PCE data for the site using EPA data useability guidance (EPA 1992a).

3. Estimate breathing-zone PCE vapor concentrations at each receptor by quantifying individual exposure pathways.

4. Adopt toxicity benchmark values for PCE following California Office of Environmental Health and Hazard Assessment (OEHHA) toxicity criteria database.

5. Quantitatively estimate potential cancer risk to identified receptors using EPA's Reasonable Maximum Exposure, using upper-bound input parameters where available.

6. If results are above EPA's target risk ranges, conduct probabilistic quantitative risk assessment techniques (using the probabilistic risk assessment model Crystal Ball®).

1.3 Report Organization

Section 2 of this report provides a description of the site location, background, and hydrogeology. Section 3 provides a discussion of the existing site data reviewed to support the HHRA. Section 4 provides an overview of the HHRA methodology used to develop the Conceptual Site Model and construct the exposure assessment. Section 5 presents the results of the exposure assessment, including a description of the exposure scenarios, the exposure calculations, and the modeling of breathing zone PCE vapor calculations. Section 6 is the toxicity evaluation for PCE, and Section 7 provides a summary of the risk characterization results. Section 8 presents the conclusions and recommendations, and Section 9 lists the references used to prepare the report.

2 SITE DESCRIPTION, HISTORY, AND BACKGROUND

2.1 Site Description

The Villa Street project site is located at 1710 Villa Street in Mountain View, California. The 2.04-acre site is vacant. It was previously the site of offices and warehouses associated with Jasco operations. The warehouses were demolished in 2002. The property owners also own the four adjacent 0.14-acre parcels zoned for single-family lots to the west facing Villa Street. Figure 1 shows the location of the project site relative to the four single-family homes, other adjacent properties, local roadways, and the adjacent railroad tracks. For the scope of this risk assessment, only the 2.04-acre Jasco site is identified as the "study area" because these four single-family lots are not part of the Superfund site, there has been no indication of contamination at the lots, and because the groundwater PCE plume, in general, flows northwards away from the single-family lots. As noted in Section 1, Jasco is not believed responsible for contamination of groundwater or soil by PCE.

The 2.04-acre Jasco site is currently surrounded by multi-unit residential properties to the east, south and west, while railroad tracks and the Central Expressway are located to the north. The site was historically used by Jasco as a chemical blending and repackaging facility. In 1985, the zoning for the site changed from industrial to allow residential as well as research & development uses, and the Jasco facility terminated its operations in 1995.

As noted in the introduction, numerous activities, including remedial action for site contamination, have taken place to implement EPA's ROD, including soil excavation and groundwater monitoring to evaluate the efficiency of the remedial activities. PCE was not addressed in the ROD because it was not detected in site groundwater until 1993. However, the remedial actions taken(groundwater extraction and treatment, hydraulic control, and soil vapor extraction) are assumed to have treated some of the newly-discovered PCE as well as the other chemicals of concern for the site.

2.2 Site Hydrogeology

Previous studies have identified three water-bearing zones beneath the Villa Street site, including the "perched" zone and the A- and B-aquifers (IT Corp 2000) (Figure 2). The perched zone extends from 15 to 18 feet below ground surface (bgs). The groundwater flow direction and the gradient for the perched zone are currently undetermined. The A- and B-aquifer units occur from 30 to 48 feet bgs and 40 to 60 feet bgs, respectively. The groundwater for both aquifers flows across the site in a north-northeast direction. As shown on Figure 2, soil permeability between the perched zone, the A-aquifer, and the B-aquifer generally diminishes with increasing depth, ranging from relatively loose and somewhat permeable (e.g., silty sand) to tight and relatively impermeable (e.g., clay layers).

A possible C-aquifer also lies beneath the Villa Street site. The PCE Report noted the possible existence of a C-aquifer located some 20 to 40 feet beneath B-aquifer, approximately 150 feet bgs at their study area (about 1.5 miles from the project site). According to this study, the aquitard between the B- and C-aquifers is composed of a series of relatively impermeable clay layers. (IT Corp 2000).

EPA has reported that the C-aquifer is of drinking water quality (EPA 1992b). This report, however, does not address the C-aquifer because the potential for human exposure to the C-aquifer at the Villa Street site is deemed negligible. The rationale behind this assumption is: (1) the thick and relatively impermeable aquitard between the B- and C-aquifers, in addition to the layers of aquifers and aquitards between the ground surface and the C-aquifer, is expected to minimize or eliminate exposure to soil vapor originating from the C-aquifer, (2) the City's land use regulations would prohibit installation of a new water supply well at the Villa Street site regardless of groundwater contamination issues, and (3) EPA's ROD specifically prohibits the use of site groundwater for drinking purposes.

3 REVIEW OF PCE DATA FOR SOIL AND SOIL VAPOR

Various investigations of the Villa Street site have been conducted both to monitor the concentration of chemicals in site soils and groundwater, and to assess the efficiency of remedial actions. Soil vapor and geotechnical data collected for this risk assessment (November 2002) were used to estimate potential exposure from the inhalation pathway. The Johnson & Ettinger model (EQM 2000) was used to estimate exposures to future residents via vapor inhalation, and a simplified "box model" calculation was used to estimate exposures to future construction workers. This section summarizes soil data collected during prior investigations and soil vapor and geotechnical data collected for this risk assessment. This section also discusses data quality and compatibility with the data requirements, following EPA guidance for data useability in risk assessment.

3.1.1 Soil Data

Soil data for the site are summarized in Table 1. Data shown on the table consist only of samples where PCE residues were identified (no non-detects are shown). All data for soils on the project site came from the Revised PCE Investigation Report (IT Corp 2000). The PCE Report contains soil data collected during the groundwater sampling activities from 1997-1999. In brief, the PCE Report concluded that the PCE concentrations detected in all of the soil samples ranged from <0.0063 to 0.01 milligrams per kilogram (mg/kg). This is below the 7 mg/kg soil cleanup standard set forth in the ROD (EPA 1992b). No PCE was detected above the perched zone (above the site aquifers, 15 feet or less bgs). PCE was detected only in a few samples collected from 20 to 35 feet bgs. All soil samples containing PCE were collected from the eastern boundary of the site or from locations upgradient of all potential contamination sources identified at the site. The report also concluded that because of the presence of PCE in upgradient locations and the absence of PCE in the perched zone, a source for PCE in shallow soil does not exist within the Jasco site. The PCE Report also suggested that the presence of PCE in soil at lower depths definitely did result from downgradient migration of PCE-contaminated groundwater from another source area unrelated to Jasco's operations.

3.1.2 Site-Specific Soil Vapor and Geotechnical Data

A site-specific soil vapor survey was conducted by Jasco in October 2002 which, among other things, measured soil vapor concentrations, soil bulk density, and soil moisture content, all of which are important to estimating the potential for soil vapor exposure at the site. Detailed information for the on-site soil vapor survey is available in the original sampling and analysis plan (Shaw, 2002). Sampling locations and PCE soil vapor concentrations from this survey are summarized in Figure 4. All soil vapor data were obtained from 12.5 ft bgs, in the silty loam above the groundwater table. Results from this survey showed that soil vapor PCE concentrations at the site ranged from non-detected to 45,000 $\mu g/m^3$, with all of the detected values in a narrow zone at the northeastern boundary of the site.

Geotechnical samples for bulk soil density and soil moisture were taken at two vertical intervals at two of the borings. Of the four samples taken, two were in the silty loam at 10-12 ft bgs, and two were from the clay layer at 4-8 ft. bgs. The bulk density and soil moisture data were used to define the total porosity, air-filled porosity, and water-filled porosity, all of which are key input parameters for calculation of diffusion of PCE vapor through the vadose zone. As listed below all of the soil samples had relatively high moisture contents and relatively low air-filled porosities.

Soil Parameter	**Silty Loam (10-12 feet bgs)**	**Clay Layer (4-8 feet bgs)**
Dry bulk density (lbs/ft^3)	89 - 102	97.4 - 99.7
Moisture content (wt. %)	20.2 - 24.7	19.3 - 22.1
Total porosity (fractional)	0.393 - 0.472	0.408 - 0.422
Air-filled porosity (fractional)	0.063 - 0.121	0.056 - 0.121

3.1.3 Data Quality Evaluation

Site data were evaluated by generally following the EPA Guidance for Data Quality Assessment (EPA 1992a). The goal is to ensure that the quality of the data used in the risk assessment is adequate to support the findings. All data in the reports summarized above were generated using standard EPA methodology. Quality assurance and quality control procedures were reviewed for all data sets, and no anomalies were found for all data sets. All of these data sets were therefore considered acceptable for use in this risk assessment.

4 OVERVIEW OF HHRA METHODOLOGY

4.1 Summary

This document was performed in general accordance with EPA and California Office of Environmental Health Hazard Assessment (OEHHA) risk assessment guidelines (OEHHA 2000, EPA 2001, EPA 1989a). Potential sources of PCE, mechanisms of transport, and potential PCE exposure pathways are identified, and this information is then summarized in a conceptual evaluation model (Figure 3), which forms the basis of the risk assessment.

In the exposure assessment phase, conservative (i.e., protective) exposure scenarios and input parameters are quantified (estimated) for each receptor identified in the problem formulation phase. Only potentially complete exposure pathways with potential human exposure are evaluated in this risk assessment, consistent with EPA and Cal-OEHHA risk assessment guidelines. Exposures are quantified by combining existing soil data and the additional soil vapor and geotechnical data with key exposure parameters.

The Johnson & Ettinger soil vapor exposure model (EQM 2002) is used to derive exposure point concentrations via the inhalation exposure pathway. In addition, EPA and OEHHA guidelines are followed to derive exposures for all exposure pathways (e.g., EPA 1989a, 2001, OEHHA 2000). Exposures to receptors are quantified using the most conservative assumptions, roughly equivalent to EPA's Reasonable Maximum Exposure (RME) guidelines. Exposure estimates are then combined with EPA toxicity benchmark values (e.g. a cancer slope factor for suspected carcinogens such as PCE) to generate risk estimates. If the resulting risk values are within the acceptable range, no further analysis would be necessary. If risk values exceed EPA's target risk range (generally regarded as 10^{-4} to 10^{-6}, or one-in-ten-thousand to one-in-a-million) cancer risk range, then further analysis would be conducted to evaluate the potential risks at various exposure levels.

A brief toxicological assessment was conducted to review and eventually adopt the most appropriate toxicity benchmark values, which for PCE is a cancer potency slope value for the inhalation pathway of 1.5×10^{-1} $(mg/kg\text{-}d)^{-1}$ (OEHHA 2002). Exposure estimate doses were then combined with this cancer potency slope value to yield the quantitative estimates of human cancer risk.

If preliminary (deterministic) calculations indicate that risk range values are exceeded, probabilistic quantitative risk assessment techniques (using Crystal Ball®) would then be used to generate a range of cancer risk estimates to residents and construction workers. This model incorporates statistical ranges of numerous input parameters (generally categorized as contaminant data, exposure parameters, and toxicity values) to generate estimates of risk. Results are depicted as a range of estimated cancer risks for exposure to PCE, addressing both short- and long-term exposures in addition to locations potentially causing concern or associated with specific levels of risk.

Table 1. Summary of Soil Data Used to Support the Human Health Risk Assessment

Source	Purpose of Data Collection	Date	Sample ID	Sampling Results		QA/QC Review
				PCE Concentration Range (mg/kg)	Depth Below Ground Surface (ft)	
Revised PCE investigation report	Soil and groundwater survey activities	1997-1998	HP-1 to HP-7, HP-9, HP-10, HP-16, HP-17, HP-43, HP-44	0.0063 u	6.5 - 19.5	Acceptable
				0.0095 - 0.01	20 - 35	

u = below analytical detection limit

4.2 HHRA Conceptual Site Model

The problem formulation phase involves identifying mechanisms of potential human exposure to PCE, including potential receptors and PCE sources, transport mechanisms, and exposure pathways. For this risk assessment, two key receptor groups were identified: construction workers and future residents at the project site (Figure 3). Based on findings of the Revised PCE Investigation Report (IT Corp 2000), it is assumed that PCE is transported from upgradient off-site groundwater sources into groundwater under the Villa Street site. Because PCE is volatile, residues in the groundwater could potentially migrate vertically through the soil column and release at the ground surface, or at any point between the water table and the ground surface, as soil vapor.

To address this possibility, two potential exposure pathways were considered as part of the analysis. These potential pathways are inhalation exposure of both construction workers and future residents to soil vapor. Surface soil and subsurface soil pathways are incomplete because PCE-contaminated soils are located below the perched zone and excavation below the perched zone is very unlikely. Groundwater pathways were also incomplete because the site remedy specified in the ROD prohibits the use of groundwater for drinking purposes. Figure 3 is a conceptual model summarizing these exposure elements, including contaminant sources, transport mechanisms, the impact media, receptors, and the potential exposure pathway.

5 EXPOSURE ASSESSMENT

The objective of the exposure assessment is to quantify potential exposures to each receptor using the exposure scenarios presented by the conceptual site model (Figure 3). EPA and Cal-OEHHA guidelines were followed to derive exposures for the identified potentially complete exposure pathways (e.g. EPA 1989a, 2001a, OEHHA 2000). As described previously, vapor inhalation by onsite construction workers and future residents were the sole exposure pathways considered. Therefore, the exposure assessment focused on estimating the breathing-zone PCE vapor concentrations for each exposure scenario.

The Johnson & Ettinger soil vapor model (EQM, 2000) was used to estimate the exposure point concentrations for the inhalation exposure pathway for potential residents. The simplified "box model" was used to estimate the exposure point concentrations for the inhalation exposure pathway for future construction workers inside the unlined excavation for an underground parking garage. In general, conservative assumptions were used first to approximate EPA's Reasonable Maximum Exposure (RME) exposure scenarios. In the statistical terms used in probabilistic risk assessment, this scenario is represented (or approximated) by the upper 95th percentile.

5.1 Exposure Scenarios

As noted above, the two receptors evaluated for this risk assessment are construction workers and future site residents. Based on the conceptual site model and available data (Figure 3), one short-term exposure scenario and two long-term exposure scenarios were considered to address this potential for exposure. Existing soil data showed that there is no PCE in soil less than 15 feet bgs. In addition, PCE that was detected in soil that was less than 15 feet bgs was located outside of the site boundary and was later removed from the site. Accordingly, the oral and dermal exposure pathways were not considered further for the risk assessment. The following is a more detailed description of the exposure scenarios considered for this risk assessment.

Location of Hypothetical "Worst-Case" Residential Building. Figure 4 shows the hypothetical location of a residential condominium unit constructed over the highest measured soil vapor concentrations. The condominium was sited in a location and physical orientation specifically to generate the maximum potential soil vapor concentrations to residents hypothetically inhabiting the building. Assumptions included:

- The assumed size of the condominium was 35 feet wide and 50 feet long, which reflects the typical size of existing condominiums near the site.
- The condominium was placed as close as possible to soil vapor probe VS-10, which displayed the highest measured soil vapor concentration.
- The hypothetical location accounts for an assumed 20-foot setback from the property line.

By linearly interpolating from the measured soil vapor concentration data, the average soil vapor concentration under the 1,750 square foot building footprint would be 22,500 $\mu g/m^3$. That average concentration constitutes the worst-case value for purposes of estimating potential human health risks. As shown in Figure 4, the potential for soil vapor exposure exists only in a relatively small portion of the site. If the hypothetical building was placed 50 feet in any direction away from the worst-case location, then the average soil vapor concentration would decrease by a factor of 5 to 10. As noted in Figure 4, PCE soil vapor concentrations were below detection limits at distances more than 75 feet from the "worst-case" building location.

Scenario C1, Temporary Construction Workers Inside Underground Garage Excavation. Figure 5 shows the assumed configuration of the temporary excavation used to construct a 12-foot deep underground garage beneath the condominium. The bottom of the excavation was assumed to be 12 feet below ground surface, or 0.5 feet above the location of the soil vapor sample. The assumed annual-average outdoor wind speed above the excavation was 5 miles per hour (mph), based on data for the Bay Area from the National Climatic Data Center. The wind speed within the subsurface excavation would be lower than the above-ground wind speed. For the PCE exposure assessment it was assumed the average wind speed inside the excavation would be 1/10 the above-ground wind speed, or 0.5 mph.

The exposure scenario conservatively assumed that soil vapor diffuses vertically upward and enters the excavation only through its unpaved floor. Detailed equations used to calculate the vapor flux are described later in this report. The vapor flux rate through the floor was calculated assuming molecular diffusion through the 0.5 foot vadose zone below the floor of the excavation. The effective diffusion coefficient through the damp soil column was calculated based on site-specific bulk density and soil moisture data obtained by Jasco. The PCE entering the excavation would be diluted and ventilated by low-speed wind blowing through the excavation. A simplified "box model" calculation was used to estimate the average PCE vapor concentration inside the excavation The estimated upper-bound PCE concentration inside the excavation is 0.11 $\mu g/m^3$.

Workers inside the excavation were assumed to be exposed to PCE vapors only during the period of actual construction, calculated as 8 hours per day for 350 construction days. It was assumed the construction workers would then leave the site permanently, and would no longer be exposed to potential PCE vapors from the site.

Scenario R1, Slab-on-Grade Residence without Underground Garage. Figure 6 shows the assumed orientation for this scenario. The condominium was assumed to include a single story residence, constructed using conventional slab-on-grade methods with no underground garage, consistent with current construction practices found in Mountain View. The building was assumed to use modern, weather-tight construction with the windows closed year-round, and it was conservatively assumed the building's ventilation system would induce an indoor vacuum that would increase soil vapor intrusion through the slab foundation.

The Johnson-Ettinger model was used to estimate the indoor PCE concentration, assuming soil vapor would migrate upward through 3.5 feet of moist silty loam (LS) and 9 feet of moist clay (CL) between the measured soil vapor sampling interval and the bottom of the building slab. Detailed assumptions used to model the indoor vapor concentration are described later in this report. The maximum indoor PCE concentration inside the building was modeled to be 0.7 $\mu g/m^3$.

Scenario R2, Above-Ground Residence with Underground Garage. Figure 7 shows the assumed orientation. The condominium was assumed to include a single story residence overlying an underground garage. The above-ground floor of the building was assumed to use modern, weather-tight construction with a low air exchange rate. However, the garage was assumed to be unheated and constructed using only nominal weatherproofing, and it was assumed the garage doors would occasionally be opened to allow cars to enter or exit the garage. In that case, the air exchange rate through the garage would be relatively high. Only a small fraction of the air in the naturally ventilated garage would be drawn into the weather-tight occupied portion of the building. Thus, the garage would serve as a *de facto* vapor barrier, shielding the above-ground residential portion of the condominium from soil vapor migrating upward from the groundwater table. Any soil vapor that penetrated into the garage would be greatly diluted through dispersion, ventilated away from the occupied portions of the building.

Details on the methods used to estimate indoor PCE concentrations are described later in this report. The Johnson-Ettinger model was used to estimate the indoor PCE concentration in the underground garage, assuming soil vapor would have to migrate upward through 0.5 feet of moist silty loam. It was assumed there would be no indoor vacuum in the garage because it would be unheated and would be frequently open to the outside. The air exchange rate for the underground garage was assumed to be 1.26 exchanges per hour, which is the upper end of the range of residential buildings recommended by EPA's guidance document (EQM, 2000). The maximum indoor PCE concentration inside the garage was modeled to be 0.018 $\mu g/m^3$. Finally, it was assumed that only 1/10 of the air from the garage would be drawn into the occupied upper story, in which case the PCE concentration inside the above-ground (occupied) portion would be estimated at 0.002 $\mu g/m^3$.

5.2 Exposure Calculations

Inhalation exposures for residents were estimated using the exposure equations presented in Johnson & Ettinger (EQM 2000), discussed in Section 5.4.

Tables 2 and 3 summarize the exposure parameter values used in the risk assessment for the future residents and construction workers, respectively, as recommended by OEHHA (2000).

Table 2. Summary of Exposure Parameters Used to Evaluate Potential Residential Exposures to PCE in Groundwater, Soil, and Soil Vapor at the Villa Street Site

Exposure Parameter	Referenced Values	Reference Source
Exposure frequency (EF)	350 days/year	OEHHA 2000
Exposure duration (ED)	30 years	
Averaging time (AT)	25,550 days	
Inhalation Absorption Factor (A)	1	
Daily breathing rate [BR/BW]	bL/kg-day	
Notes: b = Gamma distribution; Loc = 193.27, scale = 31.27, shape = 2.46 and range = 175-425		

Table 3. Summary of Exposure Parameters Used to Evaluate Potential Construction Worker Exposures to PCE in Groundwater, Soil, and Soil Vapor at the Villa Street Site

Exposure Parameter	Referenced Values	Reference Source
EF	90 days/year	EPA 1997
ED	1 year	EPA 1997
ET	8 hours/day	*
A	1	OEHHA 2000
[BR/BW]	1170.72 L/kg-day	
AT	25,550 days	
Notes: * indicates values assumed base on professional judgment		

5.3 Modeling of Breathing Zone PCE Vapor Concentrations

This human health risk assessment was conducted based on the best available data for the site, including on-site measurements of soil vapor concentration, soil stratigraphy, soil porosity, and soil moisture. These data were incorporated into the Johnson & Ettinger exposure model (EQM 2000) and the simplified "box model" to estimate potential inhalation exposure to indoor receptors occupying a hypothetical building constructed over the most heavily contaminated portion of the site. While specific limitations and uncertainties have been identified for these models, the models are expected to be the most effective tool available for this purpose. Equations used in the Johnson & Ettinger vapor intrusion model are presented in Johnson & Ettinger (EQM 2000).

The equations used in the simplified "box model" to calculate the PCE vapor concentrations inside the open excavation during the construction phase of the project are listed below:

$$D^{eff} = D^{air}\left(\frac{q_v^{3.33}}{q_T^2}\right)+\left(\frac{D^{H_2O}}{H_i}\right)\left(\frac{q_m^{3.33}}{q_T^2}\right) \text{..Equation (1)}$$

Where:

D^{eff} = effective diffusion coefficient (cm^2/sec)

D^{air} = diffusion coefficient in air (cm^2/sec)

θ_v = volumetric vapor content (m^3-vapor/m^3-soil)

θ_T = total porosity (m^3-voids/m^3-soil)

D^{H2O} = diffusion coefficient in water (cm^2/sec)

H_i = Dimensionless Henry's Law constant ($\mu g/m^3$-vapor)/$\mu g/m^3$-H_2O)

θ_m = volumetric moisture content (m^3-H_2O/m^3-soil)

$$Flux = \left(D^{eff}\right)\left(\frac{C_v}{\Delta X}\right) \text{...Equation (2)}$$

Where:

Flux = upward soil vapor flux rate (g/sec/cm^2)

C_v = vapor concentration (g/cm^3)

ΔX = soil gas sampling depth below the bottom of excavation (cm)

$$E = (Flux)(A_{bottom}) \text{..Equation (3)}$$

Where:

E = rate of mass exchange (g/s)

A_{bottom} = area of bottom of excavation (cm^2)

$$VR = (V_{wind})(A_{side}) \text{..Equation (4)}$$

Where:

VR = ventilation rate (m^3/s)

V_{wind} = wind velocity (meters/second)

A_{side} = area of side of excavation (m^2)

Based on the above box model exposure equations, it would now be possible to calculate the concentration in the excavation hole, expressed in g/m^3, which can be input directly into the J&E vapor exposure model.

$$C_{Hole} = \frac{E}{VR} \text{..Equation (5)}$$

Where:

C_{Hole} = concentration in the excavation (g/m^3)

The project site is currently vacant and no site development plans are currently in place. It is therefore necessary to use input parameters that would be representative of a typical building under these conditions. Most uncertainties associated with model predictions would be expected to arise from the building, wind speed, or soil vapor concentration assumptions input into the models. Other uncertainties of the models are expected to be relatively small in comparison to those associated with building assumptions. By using conservative (protective) building assumptions, the model is expected to generally produce exposure predictions that are protective of the residents and construction workers on site. Tables 4a, 4b, and 4c summarize the input data and assumptions used to run the Johnson & Ettinger vapor intrusion model and the simplified "box model" to approximate RME exposures.

Table 4a. Input Parameters Used to Estimate PCE Vapor Concentration in the Excavation

Input Parameters	Input Values: Maximum of Possible Range	Input Values: Minimum of Possible Range	Comments	Source
Molecular Diffusion Coefficient in air (m^2/d)	0.072	0.072		EQM 2000
Volumetric Vapor Content (m^3-vapor/m^3-soil)	0.121	0.063	Values calculated using site specific data	Shaw 2002
Total Porosity (m^3-H_2O/m^3-soil)	0.4724	0.3935		Shaw 2002
Molecular Diffusion Coefficient in water (m^2/d)	8.2×10^{-6}	8.2×10^{-6}		EQM 2000
Henry's Law Constant [(µg/m^3 – vapor)/(µg/m^3 – H_2O)]	0.752	0.752		EQM 2000
Volumetric Moisture Content (m^3 – H_2O/m^3 – soil)	0.352	0.331	Values calculated using site specific data	Shaw 2002
Vapor Concentration (g/cm^3)	2.25×10^{-8}	2.25×10^{-8}	Interpolated using site-specific values	*
Soil Gas Sampling Depth Below the Bottom of Excavation (cm)	15.24	15.24		Shaw 2002
Area of Bottom of Excavation (ft^2)	1750	1750		*
Wind Speed (mph)	0.5	0.5		NOAA 2001
Area of Side of Excavation (ft^2)	420	420		*
* Values assumed based on best professional judgment				

Table 4b. Input Parameters to Johnson & Ettinger Vapor Intrusion Model for Calculation of Residential Exposure (Without Underground Garage)

Input Parameters	Input Values: Maximum of Possible Range	Input Values: Minimum of Possible Range	Comments	Source
CAS Number	127184	127184		EQM 2000
Soil Gas Concentration (µg/m^3)	22500	22500	Interpolated using site-specific values	*
Average Soil Temperature (^oC)	20	14		IT Corp 1998c

Input Parameters	Input Values		Comments	Source
	Maximum of Possible Range	Minimum of Possible Range		
Depth Below Grade to Bottom of Enclosed Space Floor (ft)	0.5	0.5		*
Soil Gas Sampling Depth Below Grade (ft)	12.5	12.5		Shaw 2002
Thickness of Soil Stratum A (ft)	9	9	Values were estimated using the geologic logs from IT Corp 2000	*
Thickness of Soil Stratum B (ft)	0.03	.03		*
Thickness of Soil Stratum C (ft)	3.47	3.47		*
Soil Stratum A SCS Soil Type	C	C		IT Corp 2000
Stratum A Soil Dry Bulk Density (g/cm^2)	1.6	1.56		Shaw 2002
Stratum A Soil Total Porosity	0.4218	0.4082	Values were calculated using site-specific values	Shaw 2002
Stratum A Soil Water-Filled Porosity (cm^3/cm^3)	0.353	0.301		Shaw 2002
Stratum B Soil Dry Bulk Density (g/cm^3)	1.64	1.42		Shaw 2002
Stratum B Soil Total Porosity	0.4724	0.3935	Values were calculated using site-specific values	Shaw 2002
Stratum B Soil Water-Filled Porosity (cm^3/cm^3)	0.352	0.331		Shaw 2002
Stratum C Soil Dry Bulk Density (g/cm^3)	1.64	1.42		Shaw 2002
Stratum C Soil Total Porosity	0.4724	0.3935	Values were calculated using site-specific values	Shaw 2002
Stratum C Soil Water-Filled Porosity (cm^3/cm^3)	0.352	0.331		Shaw 2002
Enclosed Space Floor Thickness (inches)	6	6		*
Soil-bldg Pressure Differential (Pa)	20	0		EQM 2000
Enclosed Space Floor Length (ft)	50	50		*
Enclosed Space Floor Width (ft)	35	35		*
Enclosed Space Height (ft)	10	10		*
Floor-Wall Seam Crack Width (cm)	1	0.05		EQM 2000
Indoor Air Exchange Rate (1/hr)	1.26	0.18		EQM 2000*
* Values assumed based on best professional judgment				

Table 4c. Input Parameters to Johnson & Ettinger Vapor Intrusion Model for Calculation of Residential Exposure (With Unoccupied Underground Garage)

Input Parameters	Input Values: Maximum of Possible Range	Input Values: Minimum of Possible Range	Comments	Source
CAS Number	127184	127184		EQM 2000
Soil Gas Concentration (µg/m^3)	22500	22500	Interpolated using site-specific values	*
Average Soil Temperature (^oC)	20	14		IT Corp 1998c
Depth Below Grade to Bottom of Enclosed Space Floor (ft)	12	12		*
Soil Gas Sampling Depth Below Grade (ft)	12.5	12.5		Shaw 2002
Thickness of Soil Stratum A (ft)	12	12	Values were estimated using the geologic logs from IT Corp 2000	*
Thickness of Soil Stratum B (ft)	0.03	.03		*
Thickness of Soil Stratum C (ft)	0.47	0.47		*
Soil Stratum A SCS Soil Type	LS	LS		IT Corp 2000
Stratum A Soil Dry Bulk Density (g/cm^2)	1.64	1.42		Shaw 2002
Stratum A Soil Total Porosity	0.4724	0.3935	Values were calculated using site-specific values	Shaw 2002
Stratum A Soil Water-Filled Porosity (cm^3/cm^3)	0.352	0.331		Shaw 2002
Stratum B Soil Dry Bulk Density (g/cm^3)	1.64	1.42		Shaw 2002
Stratum B Soil Total Porosity	0.4724	0.3935	Values were calculated using site-specific values	Shaw 2002
Stratum B Soil Water-Filled Porosity (cm^3/cm^3)	0.352	0.331		Shaw 2002
Stratum C Soil Dry Bulk Density (g/cm^3)	1.64	1.42		Shaw 2002
Stratum C Soil Total Porosity	0.4724	0.3935	Values were calculated using site-specific values	Shaw 2002
Stratum C Soil Water-Filled Porosity (cm^3/cm^3)	0.352	0.331		Shaw 2002
Enclosed Space Floor Thickness (inches)	6	6		*
Soil-bldg Pressure Differential (Pa)	0	0		*
Enclosed Space Floor Length (ft)	50	50		*
Enclosed Space Floor Width (ft)	35	35		*
Enclosed Space Height (ft)	12	12		*
Floor-Wall Seam Crack Width (cm)	1	0.05		EQM 2000

Input Parameters	Input Values		Comments	Source
	Maximum of Possible Range	Minimum of Possible Range		
Indoor Air Exchange Rate (1/hr)	1.26	1.26		EQM 2000*
* Values assumed based on best professional judgment				

5.4 Estimated Breathing Zone PCE Vapor Concentrations

The estimated breathing zone PCE vapor concentrations for each exposure scenario were as follows:

- The simplified "box model" estimated the construction workers inside the 12-foot deep excavation would be exposed to a worst-case PCE vapor concentration of 0.11 µg/m^3.
- The Johnson & Ettinger vapor intrusion model estimated the indoor PCE concentration inside the slab-on-grade house without an underground garage to be 0.7 µg/m^3.
- The Johnson & Ettinger vapor intrusion model estimated the indoor PCE concentration inside the above-ground house with an underground garage to be 0.002 µg/m^3.

These breathing zone concentration values were incorporated into the risk characterization equations.

Worker protection under Cal/OSHA. Both the simplified "box model" and the Johnson & Ettinger model predicted airborne concentrations of PCE well below current occupational air quality standards for worker exposure. Allowable airborne concentrations of toxic compounds in the workplace are regulated by Cal/OSHA under the California Occupational Safety and Health Standards Title 8, Chapter 40, Section 5155, Airborne Contaminants. The allowable workplace exposure is expressed as the Permissible Exposure Limit (PEL), which is the time-weighted average concentration that a worker is allowed to breathe during an 8-hour work day. Another useful indicator of indoor PCE concentration is the odor detection threshold, the concentration at which most people can detect the presence of a specific substance. As shown in Table 5, the highest modeled airborne PCE concentrations are several orders of magnitude less than either the worker exposure PEL or the odor detection threshold. This indicates that PCE vapors originating from contaminated groundwater near the Villa Street property would not be expected to pose any significant risks to construction workers excavating underground garages as part of any future site development.

Table 5. Comparison of Predicted PCE Concentrations with Regulatory Limits for Worker Exposure

Item	Value ($\mu g/m^3$)
Upper 95th Percentile estimated PCE concentration in the open, unlined excavation during construction of the 12-foot-underground garage	0.114
Cal/OSHA PEL	170,000
Odor detection threshold (EPA 1992c)	12,000

6 TOXICITY DATA FOR PCE

PCE is regarded by EPA and OEHHA as a potential human carcinogen and was evaluated as such for the purposes of this risk assessment. Accordingly, EPA and OEHHA have published cancer slope factors and unit risk factors (URF) for inhalation pathways based on the most recent acceptable toxicity (laboratory animal or epidemiologic, human-based) data available. The inhalation cancer slope factor for PCE was most recently updated by OEHHA in July 2002 to 1.5×10^{-1} $(mg/kg\text{-}d)^{-1}$ (OEHHA 2002). This updated value was based on the new data from the Public Health Goal for Tetrachloroethylene in Drinking Water (OEHHA 2001), and was based on recent laboratory animal and epidemiologic data. Specifically, this included the observed incidence of leukemias in both sexes of rats tested via the inhalation route. In addition, epidemiologic data for humans are available for neurotoxicity; no human carcinogenicity has been documented to date. The most current unit risk factor for PCE was obtained from the interim toxicity criteria provided by EPA's Superfund Health Risk Technical Support Center, Environmental Criteria Assessment Office in Cincinnati, Ohio. The derived value is 5.8×10^{-7} $(\mu g/m^3)^{-1}$.

7 RISK CHARACTERIZAITON

The objective of the risk characterization is to combine the breathing zone PCE concentrations and OEHHA's cancer slope factor to generate estimated cancer risk values for identified receptors. Guidance from EPA (e.g., EPA 1989a) as well as Cal-OEHHA (e.g., OEHHA 2000) was used to estimate the risks to receptors by using the most conservative assumptions first. If the risk values were within EPA's target risk range of 10^{-6} to 10^{-4} as stated in the ROD (EPA 1992b), then no further analysis would be conducted. However, if the risk values were greater than this risk range, then Crystal Ball® would be used to generate a probabilistic estimate of cancer risk associated with PCE.

7.1 Cancer Risk Equations

OEHHA (2000) guidance was followed to calculate the probability of cancer risk associated with inhalation exposure to PCE. Inhalation risk equations used to calculate risks to future residents were as follows:

$$\text{Risk} = 0.001 \times C_{air} \times [BR/BW] \times 0.001 \times A \times (EF \times ED / AT) \times \text{Cancer Slope Factor}$$

where:

C_{air} = PCE concentration in air ($\mu g/m^3$)

(other factors were defined in the Exposure Assessment discussion)

Inhalation risk equation for future construction workers is expressed as:

$$\text{Risk} = 0.001 \times C_{air} \times [BR/BW] \times 0.001 \times A \times (EF \times ED \times (ET/24)/ AT) \times \text{Cancer Slope Factor}$$

Probabilistic risk assessment. The probabilistic risk calculations were conducted in accordance with current EPA guidance for conducting risk assessment using this approach. Probabilistic risk assessment is a powerful technique for evaluating ranges of potential risks, most effectively conducted when ranges (such as median and "upper-bound" or upper 95th percentile values) of exposure, toxicity, and other values are available for input into the model. The technique incorporates ranges of various input parameters such as the contaminant concentrations, toxicity data, receptor-specific exposure variables, and different data distributions (which are often specific to individual input variables).

The output from probabilistic risk assessment modeling is a range of risks potentially accruing from short- and long-term exposures of construction workers and future residents (adults and children), respectively. Varying individual input parameters, using a technique known as sensitivity analysis, allows for evaluation of which parameters are most likely to affect the outcome of the analysis. This can be valuable in formulating decisions concerning the site. Results of this modeling will allow for identification of specific locations that could generate potential concern or could be associated with specific levels of risk.

7.2 Risk Characterization Results

Table 6 summarizes the results from the risk characterization phase. The modeled risks are as follows:

- Construction workers inside the basement excavation for 8 hours per day for one year were estimated to have a cancer risk range of 7.1×10^{-8} (conservative upper 95th percentile) to 3.0×10^{-8} (median, more typical case) for the inhalation pathway.

- Residents living on the site for 30 years in a building with no underground garage were modeled to have a cancer risk range of 8.2×10^{-7} (median case) to 3.0×10^{-6} (upper 95th percentile).

- Residents living in an above-ground house with a 12 foot deep unoccupied basement garage were modeled to have a cancer risk range of 3.5×10^{-9} (median case) to 1.5×10^{-8} (upper 95th percentile).

Table 6. Summary Results of Risk Characterization by Individual Pathway and Receptor

Exposure Scenario		Estimated Cancer Risk	
Type of Exposure	**Scenario Code Designation**	**Upper 95th percentile (conservative)**	**Median (typical)**
Short Term	C1, Temporary Construction Workers	7.1×10^{-8}	3.0×10^{-8}
Long Term	R1, Residential (no underground garage)	3.0×10^{-6}	8.2×10^{-7}
Long Term	R2, Residential (underground garage)	1.5×10^{-8}	3.5×10^{-9}

8 CONCLUSIONS AND RECOMMENDATIONS

Following is a discussion of the conclusions from the HHRA.

Construction workers. The estimated risks to the construction workers present for 8 hours per day for 90 days at the site over a period of 1 year, excavating to a depth of 12 feet bgs, would have a negligible cancer risk, ranging from 7.1×10^{-8} to 3.0×10^{-8} (less than one in ten million) from exposure to PCE via the inhalation pathway.

Future residents (with underground garage). Future residents living in a condominium with an underground garage for 30 years would have an estimated cancer risk ranging from 1.5×10^{-8} to 3.5×10^{-9} (less than one in ten million) resulting from inhalation exposure to PCE vapors. This is also regarded as a negligible cancer risk. Risks predicted for the "underground garage scenario" were lower than those predicted for the "without underground garage scenario" by approximately a factor of two hundred. This difference is accounted for by the presence of the underground garage, which would serve as a *de facto* vapor barrier, shielding the above-ground residential portion of the condominium from soil vapor migrating upward from the groundwater table.

Future residents (without underground garage). Estimated risks to residents in the "without underground garage scenario" slightly exceeded EPA's target range of 10^{-4} to 10^{-6} (one-in-ten-thousand to one-in-a-million). The estimated inhalation cancer risk for a slab-on-grade home with no underground garage ranged from 8.2×10^{-7} (median value) to 3.0×10^{-6} (upper 95th percentile), if the home was built directly above the highest measured soil vapor concentrations. This risk level is not expected to be problematic or excessive due to the conservative nature of the assumptions underlying this estimate.

Soil exposure to PCE. Because PCE was only detected from soil at least 20 feet bgs (which is well below the limits for allowable soil excavation at the site) , neither future residents nor construction workers would be expected to be exposed to PCE in soil via incidental ingestion or dermal exposure.

Groundwater exposure to PCE. A deed restriction has been implemented to prevent use of on-site groundwater containing contaminant concentrations exceeding cleanup levels, discussed in Section 4, Element (ii) of the ROD. Moreover, it is prohibited to use site groundwater as a drinking water source. There is therefore no potential for exposure to PCE from site groundwater.

8.1 Uncertainty Analysis

Risks to both the residents and the construction workers were predicted by using the conservative (upper 95th percentile) exposure scenarios, which were consistently higher than the risks predicted by using the median (typical) scenarios. Risk estimates for each of the inhalation pathways considered are expected to be highly conservative (protective) of each potentially exposed receptor group. For example, the hypothetical condominium unit was assumed to be constructed over the highest measured soil vapor concentrations at the site. Therefore actual risks to both future residents and construction workers would be lower than the estimated risks if future buildings are located in areas other than the assumed building location.

The modeled risks are also believed to be conservatively high because future residents were assumed live in weather-tight homes with windows closed year-round. This assumption minimizes the air exchange rate and maximizes the indoor-outdoor pressure differential, and therefore maximizes the modeled indoor PCE concentration. In reality, given the moderate weather conditions in Mountain View it is likely future residents would leave windows open much of the year, thereby ventilating any PCE vapor that could migrate through the floor.

Results from this risk assessment could be useful for formulating institutional controls, deed restrictions, and/or building guidelines specified under EPA's ESD report (EPA 2002) or any other documentation needed to support protective measures at the site.

8.2 Recommendations

Based on the foregoing analysis and conclusions, it is recommended that:

- No soil vapor barrier would be needed as part of construction (any underground garage or other structure would serve as an effective *de facto* soil vapor barrier).

- No additional institutional controls or deed restrictions will be needed to further mitigate or reduce residential or construction-related exposures to PCE in soil vapor at the Villa Street site.

- No long-term monitoring or further field investigations should be required because the conclusions from this HHRA are quite definitive.

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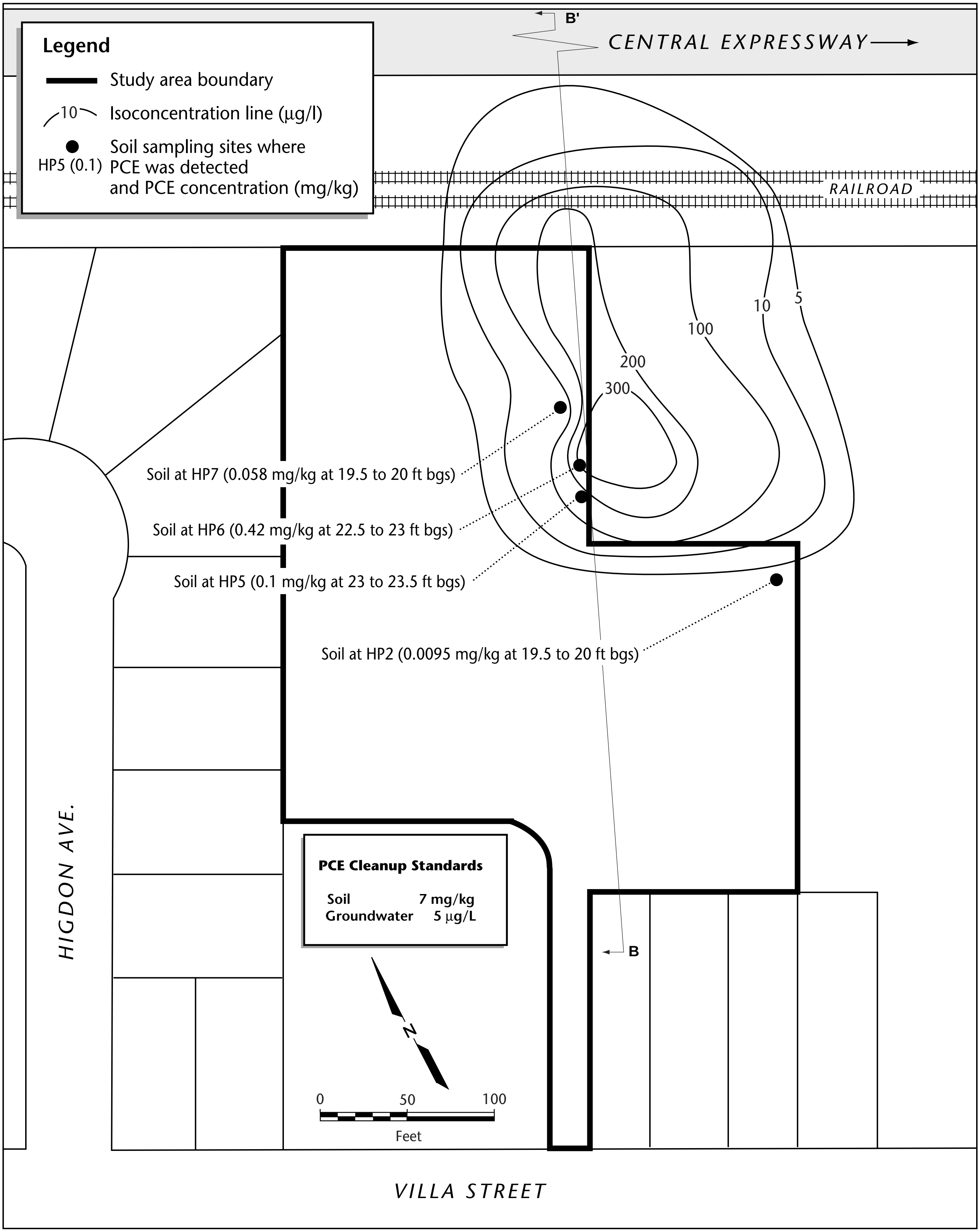

Jones & Stokes

Figure 1
Measured PCE Concentrations in Perched Groundwater Zone and Soil at the Villa Street Site

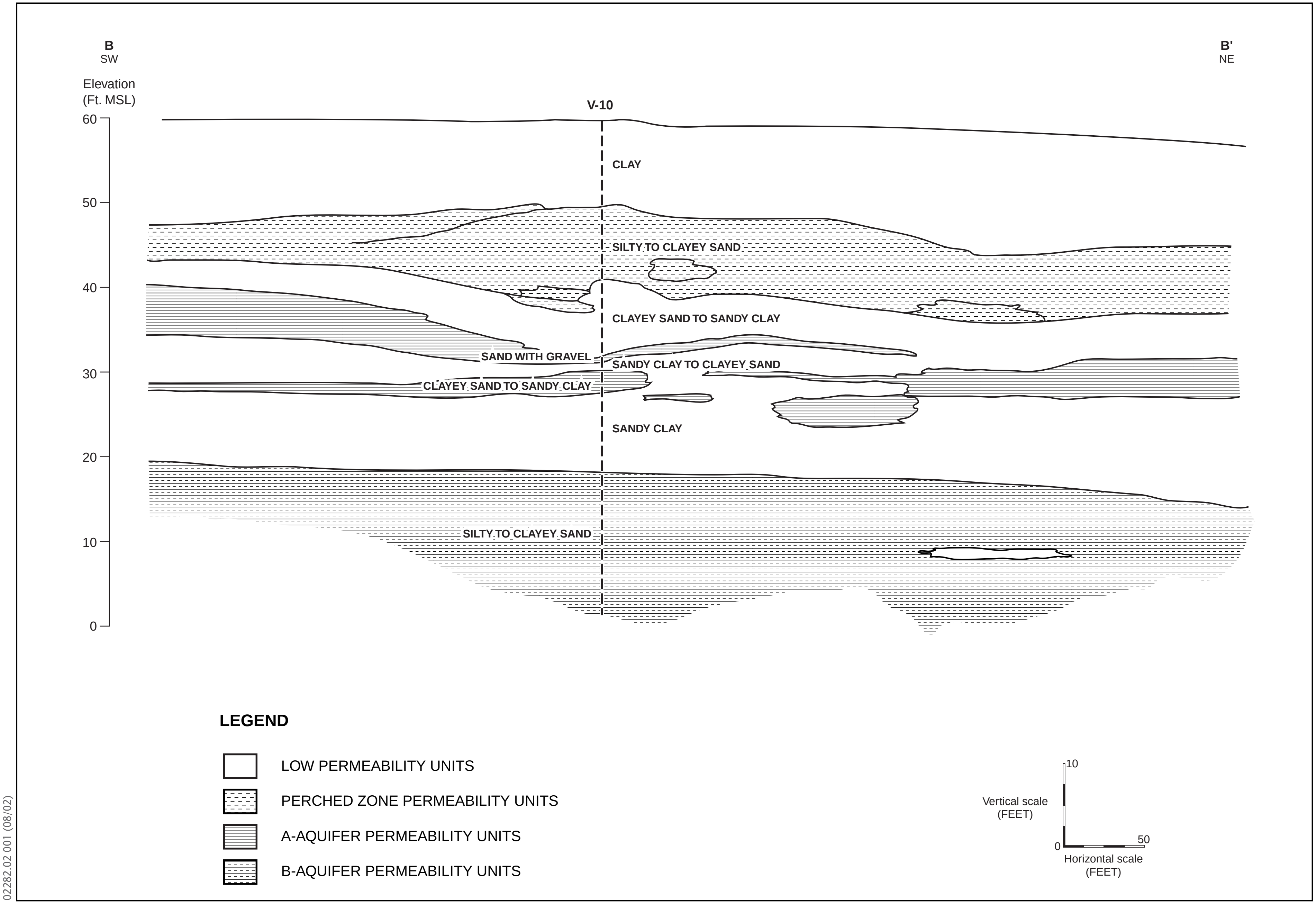

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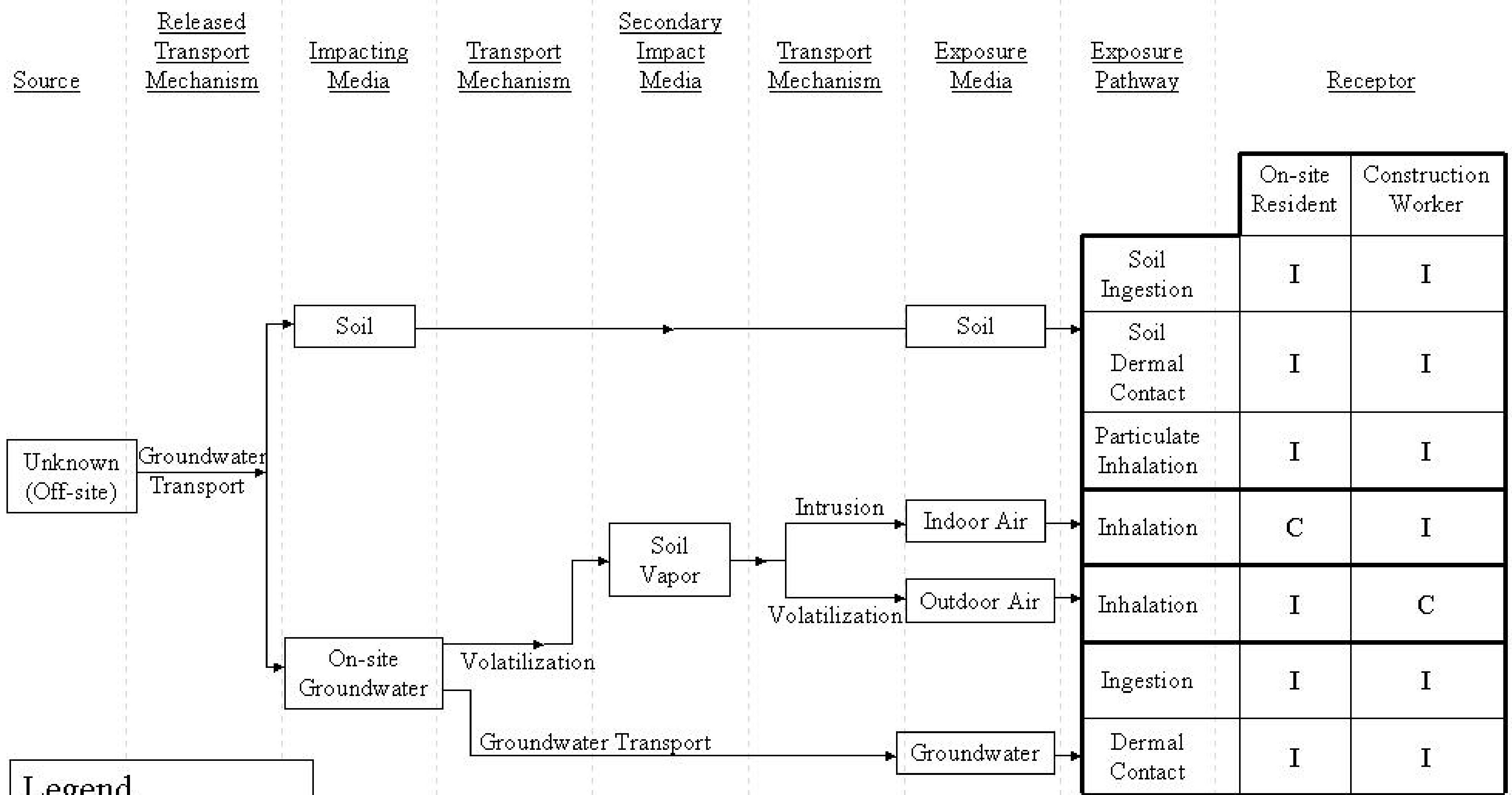
Figure 2
Geologic Cross Section B-B' of the Villa Street Site



Legend
I Incomplete Pathway
C Complete Pathway

Figure 3. Conceptual Site Exposure Model for PCE in Groundwater, Soil and Soil Vapor at the Villa Street Site

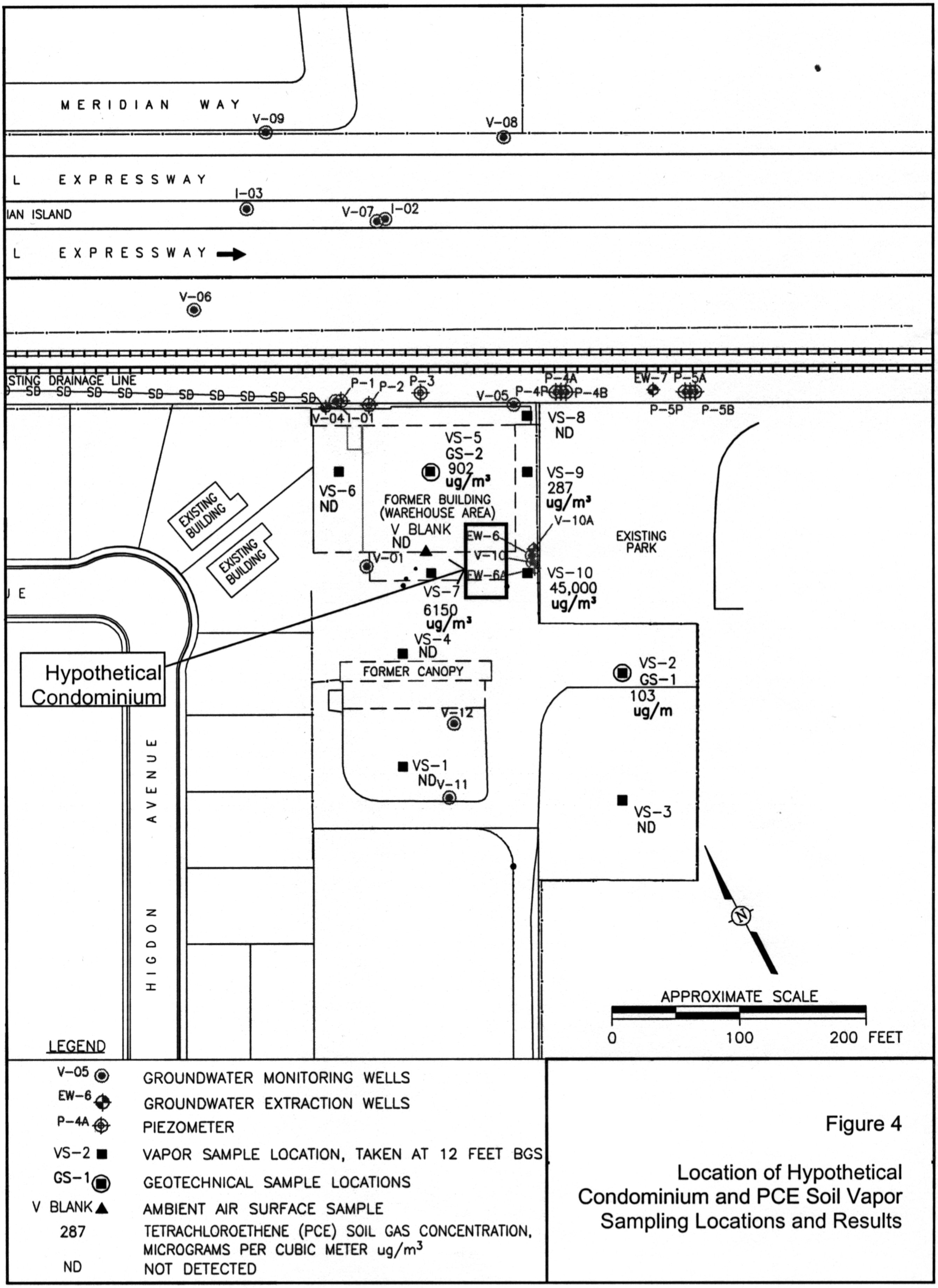


Figure 4

Location of Hypothetical Condominium and PCE Soil Vapor Sampling Locations and Results

Source: Shaw E & I, Inc.

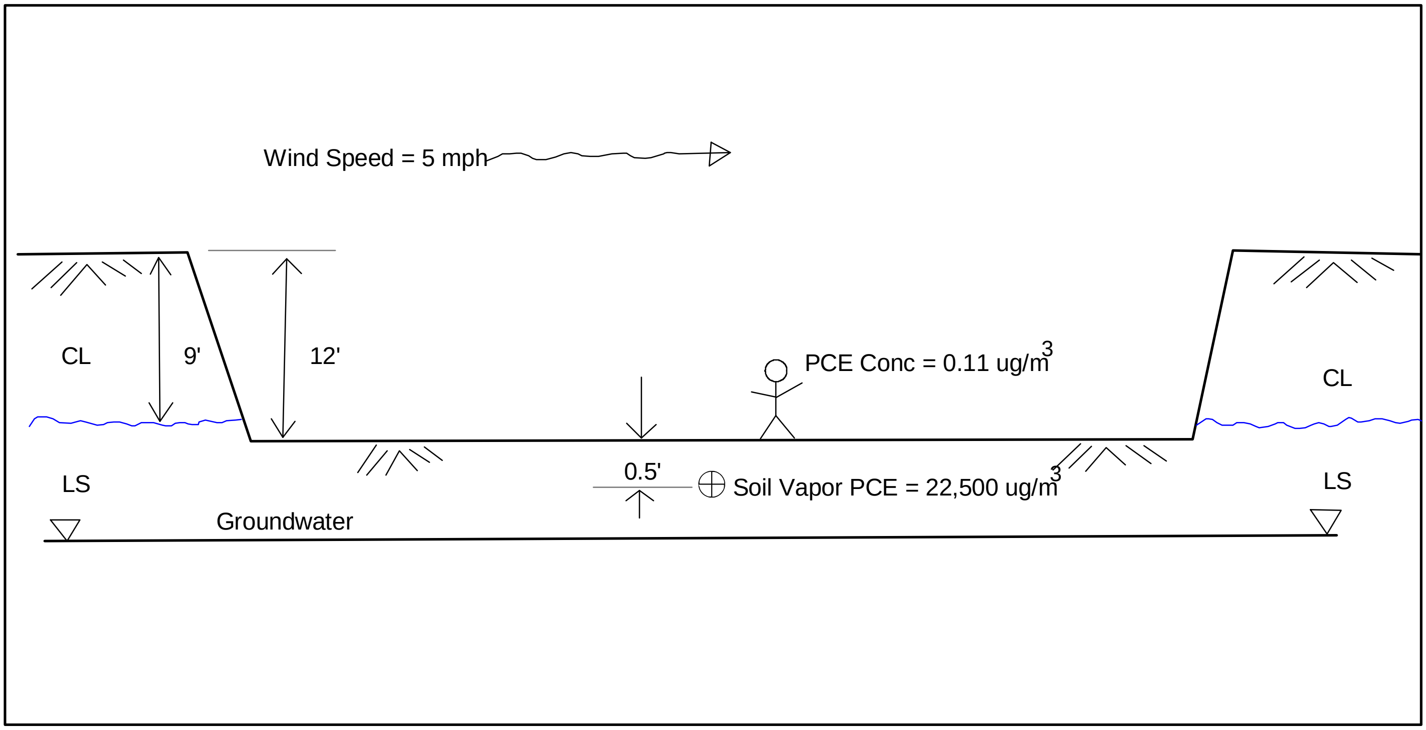
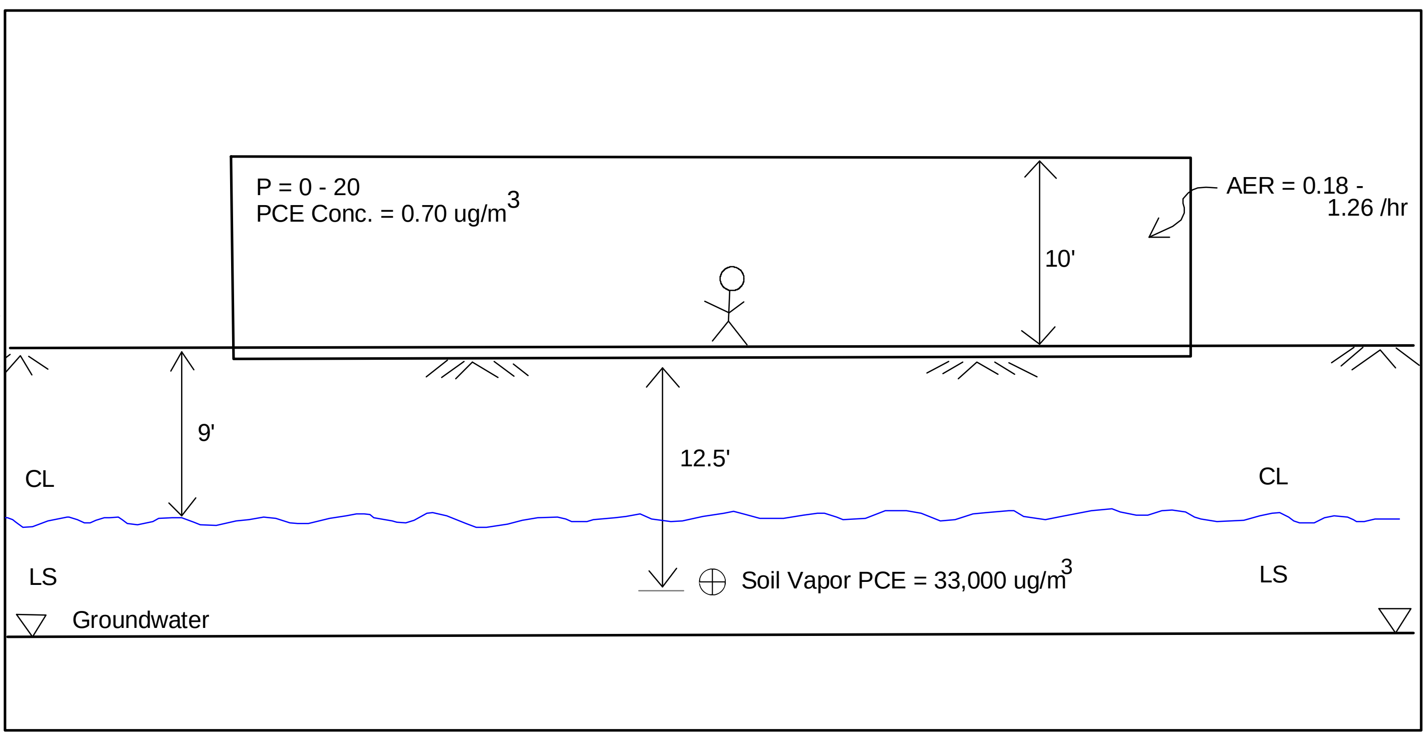


Figure 5
Scenario C1 - Construction Workers Exposure



02282.02 001 H:\PROJECTS\City_of_Mtn_View\PCE Diagrams.apr (12/30/2002)

Figure 6
Scenario R1 - Residential (No Underground Garage) Exposure

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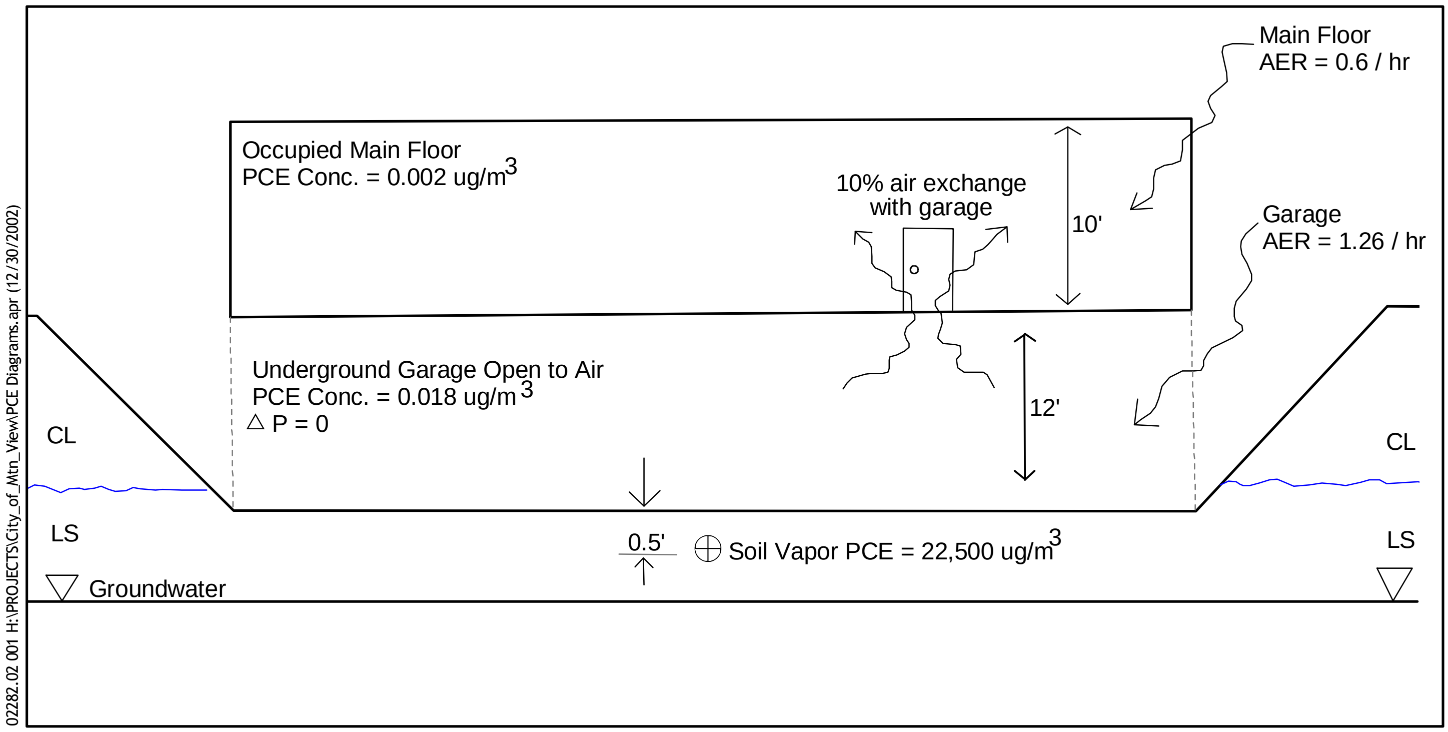

Figure 7
Scenario 2 - Residential (Underground Garage) Exposure

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